MAT JOURNALS

Journal of Control and Instrumentation Engineering
Volume 4 Issue 1

Neuroprosthetics

Anuj Tathod
Department of Electronics and Instrumentation Engineering,
Institute Of Engineering and Technology- Devi AhilyaVishwavidyalaya, Indore, INDIA
E-email: anujtathod7@gmail.com

Abstract

Neuro-prosthetics,it's far generally the study and improvement of biomedical gadgets that replaces or improves the characteristic of damaged neuromuscular organ structures. Decades of technological trends have populated the sector of neuro-prosthetics with myriad alternative strategies, neuromodulation treatment options, and rehabilitation tactics to enhance the satisfactory of existence for people with neuromotor disorders. In spite of the few but impressive medical successes, and a couple of breakthroughs in animal models, neuroprosthetic technologies remain specially limited to sophisticated laboratory environments. We summarize the core ideas and modern-day achievements in neuroprosthetics, however additionally cope with the challenges that lie alongside the direction toward clinical fruition. We advocate a pragmatic framework to personalize neurotechnologies and rehabilitation for affected person-specific impairments to achieve the timely dissemination of neuroprosthetic medicine They restore normal body processes, create or improve function, or reduce pain. Cochlear prostheses , mechanisms for bladder and bowel control, deep brain stimulation using electrodes, and devices that restore the mobility and respiration of paralyzed individuals are the examples of neuroprosthetic devices. Cochlear prostheses are the most widely used neuro-prosthetics devices. Neuroprosthetics combines neuroscience and biomedical engineering. It has become an area of intense clinical and scientific interest. In most of the neuro-prosthetics devices biosensors are employed to detect signals from the user's nervous or muscular systems. This information is forwarded to a controller located inside the device. Examples include needle electrodes implanted in muscle, wires that hit upon electrical hobby on the pores and skin, or solid-state electrode arrays with nerves growing via them. The person's nerve and the muscular structures are connected to the controller. purpose instructions are sent from the user to the actuators of the tool. after which it interprets comments from the mechanical biosensors to the person. Also for the monitoring and manipulate of the movements of the device the controller is accountable.

Spinal cord injuries- *Neuroprosthetics have been proven to be an effective and also a safe method to restore hand movement in adults suffering spinal cord injuries.*

Speech deficits-*Around 7.5 million people in the United States have trouble speaking. Maximum of these can be due to aphasias.*

Paralysis- *According to the Christopher and Dana Reeve Foundation's. Paralysis Resource Center, approximately 6 million people are still living with paralysis in the United States.*

Parkinson's disease-*Nearly 1 million people in the United States are affected by Parkinson's disease. Deep brain stimulation relieves symptoms of Parkinson's disease for numerous patients.*

Traumatic brain injury- *Around 1.7 million people in the USA are suffering from traumatic brain injury (TBI) each year.*

Alzheimer's disease- *Alzheimer's disease is a presenile dementia characterized cellularly by the appearance of unusual helical protein filaments in nerve cells (neurofibrillary tangles),*

and by degeneration in cortical regions of brain, especially frontal and temporal lobes It is projected to affect more than 107 million people worldwide by the year 2050.

Keywords:-*Neuroscience, Brain-Human Interface, Microelectrodes, Biosensors.*

INTRODUCTION

Neuro-prosthetics is the look at and development of scientific devices that update or improve the characteristic of damaged neuromuscular organ structures and restore normal frame tactics, create or improve characteristic, and/or reduce ache. Examples of neuro-prosthetics gadgets include cochlear prostheses (the most broadly used neuro-prosthetics gadgets), mechanisms for bladder and bowel control, deep mind stimulation the usage of electrodes, and devices that restore the mobility and respiratory of paralyzed individuals. in contrast to many neuro-prosthetics devices, which require implantation inside the body, WalkAide , which became developed to address foot drop, is a non-invasive device worn on the lower leg.

A subject that mixes neuroscience and biomedical engineering, neuro-prosthetics has come to be an area of excessive scientific and medical hobby and speedy progress. Cochlear implants, which had been first brought within the Fifties and Nineteen Sixties have, through the years, long gone from big, outside additives that had been strapped to the body, to smaller, internally worn gadgets. Coronary heart pacemakers, who were successfully implanted for the primary time in 1960, were in the beginning evolved as outside devices.

Most neuro-prosthetics devices employ biosensors to detect signals from the user's nervous or muscular systems and relay this information to a controller located inside the device. Examples include wires that detect electrical activity on the skin, needle electrodes implanted in muscle, or solid-state electrode arrays with nerves growing through them. The controller is connected to the user's nerve and muscular systems and the device itself. It sends intention commands from the user to the actuators of the device, and interprets feedback from the mechanical and biosensors to the user. The controller is also responsible for the monitoring and control of the movements of the device.

Many neuro-prosthetics devices use purposeful electric Stimulation (typically abbreviated as FES) to prompt nerves, innervating extremities affected by paralysis resulting from incomplete spinal twine injury (SCI), head injury, stroke or different neurological problems. FES employs small electric impulses to excite the nerves that deliver paralyzed muscle mass. This activates the ones muscular tissues, allowing them to provide basic but useful movement.

One of the problems most correctly handled by using FES is foot drop (also known as drop foot). Foot drop is a situation resulting from weakness or paralysis of the muscle tissues worried in lifting the the front a part of the foot. It makes strolling a mission, inflicting someone to both drag the foot and ft and have interaction in a high-stepping walk called steppage gait. Foot drop is not a ailment, but a symptom of an underlying hassle. it is often as a result of an interruption in the sign from the brain to the peroneal nerve, which runs alongside the out of doors of the lower leg underneath the knee.

WalkAide is a neuro-prosthetics device that channels useful electrical stimulation to the leg and foot with the intention to

repair ordinary nerve-to-muscle indicators. all through the swing segment of strolling, the WalkAide electrically stimulates the proper muscle mass that motive ankle dorsiflexion, efficiently lifting the foot at the right time. WalkAide is some of the most celebrated and fantastically appeared neuro-prosthetics innovations to be had nowadays due to the fact many people revel in instant and widespread improvement in their walking ability, enabling them to stroll quicker, further and with much less attempt. The development in the walking sample reduces the threat of falls and leads human beings to come to be more solid and unbiased of their walking. other clinical advantages of FES may encompass prevention of muscle disuse or weak spot, expanded neighbourhood blood float, muscle strengthening, and maintained or improved joint variety of motion.

Neuro prosthesis

As a steady go with the flow of media recognition has borne out, WalkAide is a number of the most celebrated and enormously appeared neuro prosthetics innovations available today. Not like many neuro prosthetics gadgets, which require implantation within the frame, WalkAide is a non-invasive device worn on the lower leg.

WalkAide is a complicated neuro prosthetic device that addresses Foot Drop (also referred to as Drop Foot, footdrop and drop foot). WalkAide can only be prescribed with the aid of a physician. as with any orthoses, a radical assessment by a credentialed and skilled medical professional will determine if WalkAide is right for a selected character. To find a skilled clinical professional in your vicinity, go to our patient Care Center Locator's

Different Forms of Neuroprosthetics

Prosthetics for pain relief

There are two main components of SCS (Spinal Cord Stimulator) which are an electrode and a generator. Masking the area of a patient's pain is the technical goal of SCS for neuropathic pain with a stimulation induced tingling, known as "paresthesia", because this overlap is necessary (but not sufficient) to achieve pain relief. The afferent nerves which are stimulated depend upon the "Parasthesia coverage".

The size, shape, arrangement, number, and assignment of contacts are the design options of electrode and how the electrode is implanted. Programming options are very numerous (a four-contact electrode offers 50 functional bipolar combinations The design option for the pulse generator include the, pulse width, target anatomic placement location, power source, current or voltage source, pulse rate, and number of independent channels. Computerized equipment uses the current devices to find the best options for use. This reprogramming option compensates for postural changes, electrode migration, changes in pain location, and suboptimal electrode placement.

In ancient times ,conventionally electrogen -ic fish was used as a shock generator to subside the unbearable pain. Specific and detailed techniques are developed by the healers to exploit the generative qualities of the fish to treat various types of pain, including headache and many other muscular pains. Because of the awkwardness and impracticality of using a living shock generator, a fair level of skill was required to deliver the therapy to the target for the proper amount of time. (Including keeping the fish alive as long as possible) Electro analgesia was the first deliberately used application of electricity. By the nineteenth century, most western physicians began to offer their

patients electrotherapy delivered by portable generator.

Auditory prosthetics (For receiving sound)
The 3 types for auditory prostheses are Cochlear implants (CIs), auditory mind stem implants (ABIs), and auditory midbrain implants (AMIs). In the cochlea, CI electrode arrays are implanted. The cochlear nucleus complicated in the decrease mind stem is inspired by way of the ABI electrode arrays. Auditory neurons inside the inferior colliculus are stimulated by means of the AMIs. Among these 3 classes Cochlear implants were very a success. Nowadays, fundamental commercial carriers of cochlea implants are the superior Bionics Company, the Cochlear organization and the Med-El business enterprise.

In assessment to conventional listening to aids that increase sound and send it thru the outside ear, the sound is then acquired and processed with the aid of the cochlear implants and is converted into electric strength for subsequent delivery to the auditory nerve. The sound from the outside environment is obtained by means of the microphone of the CI system and then it is despatched to processor. The processor then digitises the sound and filters it into separate frequency bands which are despatched to the best to no tonic place within the cochlea that about belongs to those frequencies.

Cochlear implants have been also used to permit obtaining of spoken language improvement in congenitally deaf kids, with excellent fulfilment in early implantations (earlier than 2–four years of existence were reached) there had been about 80.000 kids implanted international.
Advanced performance in cochlea implants relies upon on understanding the physical and biophysical boundaries of implant stimulation, also on an expertise of the brain's sample processing necessities. cutting-edge sign processing initiatives the maximum crucial speech statistics while providing mind the pattern recognitioninformation that it wishes. in the mind, pattern reputation is more effective than algorithmic pre-processing at identifying important capabilities in speech. to produce the proper balance of technology a mixture of engineering, sign processing, biophysics, and cognitive neuroscience became vital to maximise the overall performance of auditory prosthesis.

Motor prosthetics
Devices that support the function of autonomous nervous system. They include the implant for bladder control. Functional electrical stimulation and the lumbar anterior root stimulator are the attempts to aid conscious control of movement in the somatic nervous system.

Motor prosthetics for conscious control of movement
(Brain-computer interface)
Motor neuroprosthetics will help restore movement and the ability to communicate with the outside world to persons with motor disabilities. Researchers are currently working on it. These disabilities may include tetraplegia or amyotrophic lateral sclerosis. In motor sensory learning the stratium plays a crucial role.

The technology behind motor neuroprosth-eses is still in its primary stage or infancy. Studies and investigations on experimenting with different ways of using the prostheses are been performed lately. Having a patient think about clenching a fist, for example, produces a different result than having him or her think about tapping a finger. The filters used in the prostheses are also being fine-tuned. Researchers and doctors are investigating on creating an implant capable of transmitting signals from inside the

skull wirelessly, as opposed to through a cable.

Microelectrode arrays had been advanced to capture electrical signals from the mind that are smaller than a square centimetre. They can be implanted inside the skull to file electric pastime, transducing recorded data through a skinny cable. After a long time of research in monkeys, neuroscientists have been capable of decode neuronal indicators into movements. Some interfaces are been developed through the scientists that permit sufferers to move laptop cursors, which is a splendid step on completing the interpretation. they are beginning to build robot limbs and exoskeletons that sufferers can control through thinking about movement.

initial clinical trials advised that the devices are secure and that they've the capability to be effective. a few sufferers have worn the devices for over two years with few, if any, ill effects.previous to those improvements, Philip Kennedy (Emory and Georgia Tech) had an operable if truly primitive machine which allowed an man or woman with paralysis to spell words by using modulating their mind activity. Kennedy's tool used neurotrophic electrodes: the first was implanted in an intact motor cortical location (e.g. finger representation place) and become used to transport a cursor amongst a collection of letters. The second become implanted in a one-of-a-kind motor area and changed into used to suggest the selection. traits preserve in changing misplaced hands with cybernetic replacements with the aid of using nerves typically related to the pectoralis muscle mass. These palms allow a slightly confined range of motion, and reportedly are slated to feature sensors for detecting stress and temperature.

Dr. Todd Kuiken at Northwestern University and Rehabilitation Institute of Chicago has developed a method called targeted enervation for an amputee to control motorized prosthetic devices and to regain sensory feedback.

Bladder control implants
(Sacral anterior root stimulator)
In which a spinal wire lesion results in paraplegia, patients feel difficulty in emptying their bladders that can similarly motive contamination. From 1969 onwards Brindley advanced the sacral anterior root stimulator, which got successful human trials from the early 1980s onwards. This tool is implanted over the sacral anterior root ganglia of the spinal twine; controlled through an outside transmitter, it delivers intermittent stimulation which improves bladder emptying. It additionally assists in defecation and permits male patients to have a sustained full erection. The associated system of sacral nerve stimulation is for the manager of incontinence in capable-bodied sufferers.

Cognitive prostheses-
Cognitive prostheses are seeking to repair cognitive function to people with mind tissue loss due to injury, ailment, or stroke by using acting the feature of the broken tissue with integrated circuits. The theory of localization states that mind functions are localized to a specific part of the brain. but, recent research on brain plasticity advocate that the brain is able to rewiring itself so that a place of the mind traditionally related to a selected characteristic (e.g. auditory cortex) can carry out features related to any other portion of the mind. (e.g. auditory cortex processing visual data). Implants should take gain of mind plasticity to repair cognitive function even supposing the native tissue has been destroyed.

Sensory/motor prosthetics

In 2002 an array of one hundred electrodes became implanted without delay into the median nerve fibers of scientist Kevin Warwick. The recorded alerts were used to manipulate a robot arm developed by Warwick's colleague, Peter Kyberd and turned into able to mimic the moves of Warwick's personal arm. Additionally, a shape of sensory remarks became furnished thru the implant with the aid of passing small electrical currents into the nerve. This resulted a contraction of the first lumbrical muscle of the hand and it become this motion that turned into perceived.

Applications

Hippocampal deficits

Dr. Theodore Berger on the University of Southern California, and Drs. Sam A. Deadwyler and Robert E. Hampson at Wake woodland Baptist clinical middle, are developing a prosthetic for remedies of hippocampal detriments that includes Alzheimer's. Degenerative hippocampal neurons are the main motive of the memory issues that accompany Alzheimer's disease. The traditional case of H.M. Henry Molaison installed the role of the hippocampus inside the formation of recent recollections. also, hippocampal pyramidal cells are extremely sensitive to even brief periods of anoxia, like people who arise in the course of stroke lack of hippocampal neurons inside the dentate gyrus, an area related to this new memory formation has been attributed to blunt head trauma.Hippocampal dysfunction has also been linked to epileptic activity. This depicts the vast scope of neural damage and neurodegenerative disease conditions in accordance for which hippocampal prosthesis might be clinically relevant.

Traumatic brain injury

Around 1.7 million people in the USA are suffering from traumatic brain injury (TBI) each year. Orthosis for TBI patients to control limb movement via devices that read the neurons in brain and calculate limb trajectory, and stimulate needed motor pools to make the required movement.

Speech deficits

Around 7.5 million humans within the usa have hassle speaking. maximum of those may be due to aphasias. The success of cochlear implants advocate that cortical implants to the speech regions of the mind can be developed to improve speech in such patients.

Paralysis

Consistent with the Christopher and Dana Reeve foundation's. Paralysis aid middle, about 6 million people are nonetheless dwelling with paralysis inside the united states. Paralysis produces from many resources, annoying mind harm, stroke neurodegenerative sicknesses like a couple of sclerosis and Lou Gehrig's disease, and congenital assets. Many sufferers is probably benefitted from a prosthetic tool which monitors limb motion thru gadgets that read neurons in mind, calculate limb trajectory, and stimulate the needed motor swimming pools to make movement. This generation is being advanced at the Andersen Lab, positioned on the CaliforniaInstitute of technology. The ambitions to increase a tool to enable locked inpatients, the ones without the capacity to move or speak, to speak with others.

Parkinson's disease

Nearly 1 million people inside the united states are laid low with Parkinson's disease. Deep brain stimulation relieves signs and symptoms of Parkinson's disease for numerous sufferers. Parkinson's disease patients may want to benefit from a cortical tool that mimics the herbal alerts

needed to promote dopamine production. some other feasible road for mitigation of this ailment is a device that supplements dopamine whilst it is given with particular neuronal inputs which would permit the body alter dopamine quantity with its intrinsic sensors.

Alzheimer's disease

Alzheimer's disorder is a presenile dementia characterised cellularly through the arrival of unusual helical protein filaments in nerve cells (neurofibrillary tangles), and by means of degeneration in cortical regions of brain, specially frontal and temporal lobes it is projected to affect extra than 107 million human beings global via the yr 2050. Because of multiplied existence spans, increasingly humans are being affected by Alzheimer's sickness. Alzheimer's sickness renders people incapable of helping themselves. the various greater extreme instances of Alzheimer's patients end up in nursing houses. Even a small degree of fulfilment by cognitive implants would assist preserve Alzheimer's patients out of nursing homes.

Spinal cord injuries

Neuroprosthetics have been proven to be an effective and also a safe method to restore hand movement in adults suffering spinal cord injuries. The external sensor calculates voluntary movements that occur in the countralateral (opposite) shoulder and bases motor output commands on this logic. An implanted receiver-stimulator, an external shoulder position sensor and a terminal electrode are consisted in this neuroprosthesis. The terminal electrode is placed on the motor point of a muscle, this enables a low electrical threshold to be utilized. A radiofrequency signal is then transmitted to the implanted receiver stimulator and is later converted to electrical stimuli that depolarize the peripheral nerve. Evaluations of the neuroprosthetic are performed based on clinical outcome which measure the improvement of hand function on scales of impairment and performance of daily living.

Obstacles

Power consumption

Battery length is driven by electricity intake. Optimization of the implanted circuits reduces power wishes. Implanted gadgets currently want on-board energy assets. as soon as the battery drains out, replacement of the unit is finished with the aid of surgical procedure. Longer battery life correlates to fewer surgical procedures needed to replace batteries. One option that could be used to recharge implant batteries without surgical operation or wires is being utilized in powered toothbrushes. Inductive coupling is used to recharge batteries. any other method is to convert electromagnetic strength into electric strength, as executed in radio-frequency identification tags

Size

Implantable devices have to be extremely small to be implanted immediately in the brain or within respective organs, roughly the size of 1 / 4. Utah array is the only of the example of micro implantable electrode array. wi-fi controlling devices may be installed in exterior of the cranium and need to be smaller than a even a pager.

Mathematical modelling

Correct characterization of the nonlinear enter/output (I/O) parameters of the commonly functioning tissue to be replaced is paramount to designing a prosthetic that mimics ordinary biologic synaptic signals. Mathematical modelling of those signals is a complicated task "because of the nonlinear dynamics inherent in the mobile/molecular mechanisms comprising neurons and their synaptic connections." The output of almost all mind neurons is depending on which post-synaptic inputs are energetic

and in what order the inputs are received. (spatial and temporal residences, respectively).

as soon as the I/O parameters are modeled mathematically, integrated circuits are designed to imitate the everyday biologic alerts. For the prosthetic to carry out like regular tissue, it must system the input indicators, a system called transformation, inside the equal manner as ordinary tissue..

Biocompatibility

Cognitive prostheses are implanted at once within the mind, so biocompatibility is a very important impediment to overcome. substances used inside the housing of the device, the electrode fabric (along with iridium oxide), and electrode insulation should be chosen for long time implantation. difficulty to requirements: ISO 14708-3 2008-11-15, Implants for surgical procedure - lively implantable scientific devices part three: Implantable neuro stimulators.

Crossing the blood–brain barrier can introduce pathogens or different substances that may motive an immune response. The mind has its own immune gadget that acts in a different way from the immune gadget of the relaxation of the frame.

Questions to reply: How does this have an effect on fabric preference? Does the brain have unique pages that act otherwise and might have an effect on substances notion to be biocompatible in other areas of the frame?

Data transmission

Wi-Fi Transmission is being advanced to permit non-stop recording of neuronal indicators of individuals in their day to day life. This lets in physicians and clinicians to seize greater information, ensuring that brief term occasions like epileptic seizures can be recorded, allowing better treatment and characterization of neural disorder.

At Stanford College a small in size and light weighted device has been advanced that lets in regular recording of primate brain neurons. This era even permits neuroscientists to have a look at the mind outside of the controlled surroundings of a lab.

Techniques of information transmission should be comfortable and strong. Neuro security is a brand new warm topic. Manufacturer of cognitive implants need to avoid unwanted downloading of statistics or thoughts from and importing of detrimental data to the device that may interrupt feature.

ECONOMICS RELATED TO NEUROPROSTHETICS

According to a new report by Allied Market Research titled, "**Neuroprosthetic Market- Global Opportunity Analysis and Industry Forecast, 2013- 2020**" the global neuroprosthetics market is expected to reach $14 billion by 2020, registering a CAGR of 15.8% from 2014 to 2020. High growth segments such as Visual neuroprosthetics/retinal implants and applications such as Parkinson's disease, Overactive Bladder Syndrome and Epilepsy are expected to contribute substantially to the growth of the overall global Neuroprosthetics market. Motor Prosthetics holds the largest share within Neuroprosthetics devices market segment whereas Sacral Cord Stimulation (SCS) would maintain the leading market position through 2020, within technology segment.

Multitude of cognitive and physiological problems have a debilitating effect on 'satisfactory-of-existence' of affected patient populace. A majority (~80%) of such sufferers is unnameable to any form of treatment as first line (drug) and 2d line

(invasive surgical procedures) treatments fail. Neuroprosthetics gadgets or neural implants or mind implants provide an efficacious option to the afore-cited form of patients. Neuroprosthetics deploy technology including Deep brain Simulation(DBS),VagusNerve Stimulation (VNS), Spinal cord Stimulation (SCS) and Sacral Nerve Stimulation (SNS) depending at the clinical situation to ameliorate the ailment condition. Relying on the condition handled, product forms of Neuroprosthetics consist of Motor Prosthetics, Auditory Prosthetics/ Cochlear Implants, visual Prosthetics/ Retinal implants and Cognitive Prosthetics. Owing to various factors inclusive of excessive base of affected patient population, the affected person populace amenable to Neuroprosthetics and scope of development in QALY, the Motor Neuroprosthetics market for treating Parkinson's ailment garners the largest market percentage; Motor Neuroprosthetics for treating Overactive Bladder Syndrome and Motor Neuroprosthetics for treating Epilepsy are 2d and 1/3 biggest phase respectively. in spite of such blessings which might be high-impact increase drivers for the marketplace, excessive-fee of devices curtails the adoption fee by using sufferers, consequently restrain the market increase.

CONCLUSION

Neuromotor prostheses (NMPs) intention to replace or repair misplaced motor capabilities in paralysed people by way of routeing movement-associated signals from the brain, round broken elements of the apprehensive gadget, to external effectors. To translate preclinical consequences from intact animals to a clinically useful NMP, motion alerts need to persist in cortex after spinal cord damage and be engaged through motion purpose when sensory inputs and limb motion are lengthy absent. moreover, NMPs would require that goal-pushed neuronal interest be converted into a manipulate signal that allows beneficial obligations. Here we show initial effects for a tetraplegic human (MN) using a pilot NMP. Neuronal ensemble hobby recorded through a ninety six-microelectrode array implanted in primary motor cortex validated that intended hand motion modulates cortical spiking styles 3 years after spinal twine harm. Decoders were created, offering a ‘neural cursor’ with which MN opened simulated electronic mail and operated devices inclusive of a television, even while speaking. moreover, MN used neural manipulate to open and near a prosthetic hand, and carry out rudimentary actions with a multi-jointed robot arm. Those early results advocate that NMPs based upon intracortical neuronal ensemble spiking pastime could provide a precious new neurotechnology to repair independence for humans with paralysis.

REFERENCES

1. R. QuianQuiroga and S. Panzeri, “Extracting statistics from neuronal populations: facts theory and deciphering methods’’, Nature reviews Neurosci. Vol. 10, pp. 173-185, 2009.
2. R. A. Andersen and C. A. Buneo, “Intentional maps in posterior parietal cortex’’, Ann. Rev. Neurosci. Vol. 25, pp. 189-220, 2002
3. J. Wessberg, C. R. Stambaugh, J. D. Kralik, P. D. Beck, M. Laubach, J. okay. Chapin, J. Kim, J. Biggs, M. A, Srinivasan and M. A. L. Nicolelis, “real-time prediction of hand trajectory by using ensembles of cortical neurons in primates’’, Nature, Vol. 408, pp. 361-365, 2002.
4. M. A. L. Nicolelis, “moves from mind’’, Nature, Vol. 409, pp. 403-407, 2001.
5. M. D. Serruya, N. G. Hatsopoulos, L. Paninski, M. R. Fellows, and J. P. Donoghue, “mind-system interface: on the spot neural manipulate of a

movement sign'', Nature, Vol. 416, pp. 141-142, 2002.
6. D. M. Taylor, S. I. H. Tillery, and A. B. Schwartz, "Direct cortical control of 3D neuroprosthetic gadgets'', technology, Vol. 296, pp. 1829-1832, 2002.
7. J. M. Carmena, M. A. Lebedev, R. E. Crist, J. E. O'Doherty, D. M. Santucci, D. F. Dimitrov, P. G. PAtil, C. S. Henriquez, M. A. L. Nicolelis, "getting to know to govern a mind-gadget interface for accomplishing and grasping by primates'', PLoS Biology, Vol. 1, pp. 193-208, 2003.
8. R. A. Andersen, J. W. Budrick, S. Musallam, B. Pesaran, and J. G. Cham, "Cognitive Neural Prosthetics. developments Cognitive Sciences, Vol. eleven, pp. 486-493, 2004.
9. S. Musallam, B. D. Corneil, B. Greger, H. Scherberger, and R. A. Andersen, "Cognitive control indicators for neural prosthetics'', technology, Vol. 305, pp. 258-262, 2004.